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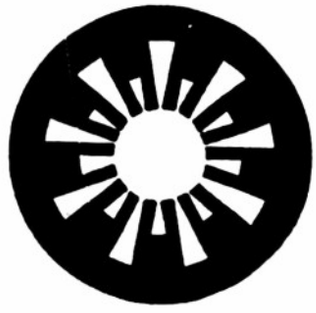
QUARTERLY REPORT

COLUMBIA RADIATION LABORATORY



April 30, 1954

COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK
New York 27, N. Y.
Physics Department

QUARTERLY REPORT

COLUMBIA RADIATION LABORATORY

Report Number Six
CU-6-54 SC-42519 Physics

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COLUMBIA UNIVERSITY
DIVISION OF GOVERNMENT AIDED RESEARCH
NEW YORK 27, NEW YORK

April 30, 1954

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(CRL Research in Progress)

(In this report the names of authors are arranged alphabetically)

PUBLICATIONS

Variation of the ℓ-type Doubling Constant in HCN
J. F. Westerkamp
Phys. Rev. 93, 716 (1954).

Examination of Methods for Detecting OH
T. M. Sanders, Jr., A. L. Schawlow, G. C. Dousmanis, and C. H. Townes
J. Chem. Phys. 22, 245 (1954).

SUMMARY

A. Magnetrons

Self-sustained oscillations have been observed in the molecular beam oscillator for the first time; that is, sustained power has been developed by the device purely as a consequence of radiation by molecules in making transitions between two allowed states. There is no dependence on external oscillators to generate the signal which stimulates the emission.

Considerable progress has been made in developing a ceramic window for the 6 mm magnetron. A tube with a peak output of 200 kw has been constructed and an average power output of 25 watts has been observed. At present, the tubes are somewhat variable in performance. It appears that improved cathodes are necessary, in addition to the ceramic windows to allow operation at high peak and average powers.

Several tunable magnetrons in the 1 cm range have been constructed. A large tuning range of about 15% has been obtained with, however, a considerable variation of power output over the range. Over a restricted range, good efficiencies have been observed.

Work on the low field magnetron is continuing. It has been possible to build a pseudo-C. W. tube at 1.3 cm which is operated on unfiltered field rectified ac. The tube operates at about 2500 gauss, and has given an output of about 17% at an efficiency of 9%.

B. Microwave Physics

Harmonic generation by silicon rectifiers has been studied further to determine the dependence of harmonic power on contact size, contact pressure, and input power. It was found that the power in the second and third harmonic of 1.25 cm radiation has two approximately equal maxima at different values of contact pressure. This behavior has not yet been adequately examined at higher harmonics.

Apparatus for the "molecular beam oscillator" has also been used as a spectrometer. It has particularly high resolution, giving line widths as small as 7 kc for NH_3. This line width is about ten times smaller than that obtained with the best microwave spectrometer of the usual type, and as a result a considerable amount of new hyperfine structure has been discovered in the spectrum of NH_3.

Experiments on the polymeric content of alkali halide beams are progressing rapidly. Dimerization varying from 78% to less than 3% has been found from observations on six alkali halides.

I. THE GENERATION OF HIGH FREQUENCIES

A. 22 Vane High Power Magnetrons at 6 mm (RPB7)

(M. J. Bernstein, N. M. Kroll, and R. Steinhoff)

Seven RPB7 tubes have been constructed and tested during the past quarter. Five of these have been provided with ceramic output windows.

RPB7-11.1A This tube, which was originally tested with a glass window (see performance chart, CRL Quarterly Report, June 30, 1953, p. 3), was remade with a ceramic window and impregnated "L" cathode. Constructional difficulties resulted in a tube which showed very poor efficiency and was characterized by arcing and unsteadiness.

RPB7-20.1A The original maximum efficiency of this tube with a glass window and "L" cathode was 29%. With a ceramic window and moly-groove-oxide cathode a maximum power output of 199 kw at a maximum efficiency of 21.5% was measured, at 20.7 kv and 44.8 amperes. The duty cycle used was .00009 (.16 μs, 550 cps). By operating at a higher duty cycle of .00019 (.35 μs, 550 cps) it was possible to obtain 24.6 watts output (128 peak kw) at an efficiency of 20.9%. At this operating point the cathode heater power was reduced to zero and the cathode temperature was about 950°C.

RPB7-22A This tube, provided with a ceramic window, was inoperable due to an accumulation of gas. It will be reprocessed after a new cathode is inserted.

RPB7-23A A ceramic window and impregnated "L" cathode were used on this tube. During the aging period the efficiency was measured as 20%. However deterioration occurred quite rapidly and operation w accompanied by arcing and moding.

RPB7-24A Operating of this tube with a ceramic window and moly-groove-oxide cathode was very poor. A maximum power output of 57 kw at 6.7% efficiency was measured. There was a great deal of moding. The ceramic window was replaced by a glass window and the tube reprocessed with the same cathode (RPB7-24.1A). Operation was much improved. However the maximum efficiency was only 16.6% and the maximum power output 130 kw.

RPB7-25A This tube contained a glass window and moly-groove-oxide cathode. There was a great deal of moding and operation was unsteady. The maximum efficiency was 14.9% at 132 kw output.

B. 22 Vane Magnetrons at 4.3 mm (RPB8)

(M. J. Bernstein)

No new tubes of this type have been made during the past quarter.

C. Harmonic Generation in Magnetrons

(M. J. Bernstein, N. M. Kroll, and W. Strauss)

An XH1 anode block has been completed and incorporated into a newly assembled pattern analyzer. Associated electric and electronic equipment is now being completed. When the system is in operating condition, the fundamental and harmonic mode spectrum of the XH1 will be investigated.

D. Crown of Thorns Tuning of Rising Sun Magnetrons

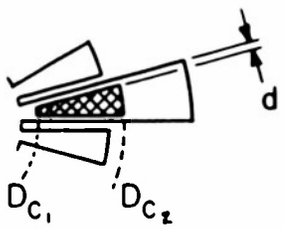
(M. J. Bernstein, N. M. Kroll, K. R. Rubin, and W. Strauss)

Two semi-closed models of the RA17[1] (with inductive pin tuning) have been constructed and hot-tested. RA17-2T, whose anode height is 0.170 in., tuned from 1.232 cm to 1.185 cm. Over this range the efficiency varied from 17.2% to 13.5%. RA17-3T, whose anode height is 0.250 in., tuned from 1.396 cm to 1.307 cm. Over this tuning range the efficiency varied from 27.8% to 13.1%. However, over the range 1.396 cm to 1.326 cm the efficiency varied only from 27.8% to 19.0%.

Inasmuch as the theoretical calculations[2] indicate very large tuning ranges for capacitive tuning, two tubes (TRA1 Series) were constructed to investigate whether such large tuning ranges could be obtained in an

operating tube. The principal tube dimensions are given below:

N = 18	D_{c_1} = 0.180 in.
D_A = 0.163 in.	D_{c_2} = 0.304
D_{M_1} = 0.288 in.	t = 0.017 in.
D_{M_2} = 0.390 in.	H_A = 0.100 in.
d = 0.005 in.	9 tuning pins used



where D_{c_1} and D_{c_2} are the diameters of the circles indicated in the figure. The performance of both tubes was quite similar, both yielding a much larger tuning range (~ 15%) than has been obtained heretofore. The efficiency varies by large amounts over the tuning range, falling to zero in the vicinity of 1.28 cm. (See Figure 1.) It has not yet been demonstrated that the tuning curve is continuous between the measured points. It is hoped that further study of tube performance in the vicinity of the minimum, together with cold test measurements, will lead to an understanding of the situation.

1. CRL Quarterly Report, Aug. 31, 1953, p. 3.
2. CRL Quarterly Report, Oct. 30, 1953, p. 2.

E. Low Field Operation of Magnetrons

(A. H. Barrett, M. J. Bernstein, N. M. Kroll, K. R. Rubin, and R. Steinhoff)

RV1 Series (20 Vane Tubes)

A new cathode consisting of a tungsten coil supported between molybdenum end hats was inserted into RV1-34 W. The cathode diameter remained .040 in. The tube (RV1-34.1 W) was tested on unfiltered, full-wave rectified 60 cycle ac. As much as 17 watts output was obtained at an efficiency of 9%. Operation began at currents as low as 10 ma. Peak voltages ranged from 3.7 to 6.2 kv at magnetic fields of 2170 to 2970 gauss. Wavelength was 1.291 cm. Operation was very close to the sub-Hartree line.

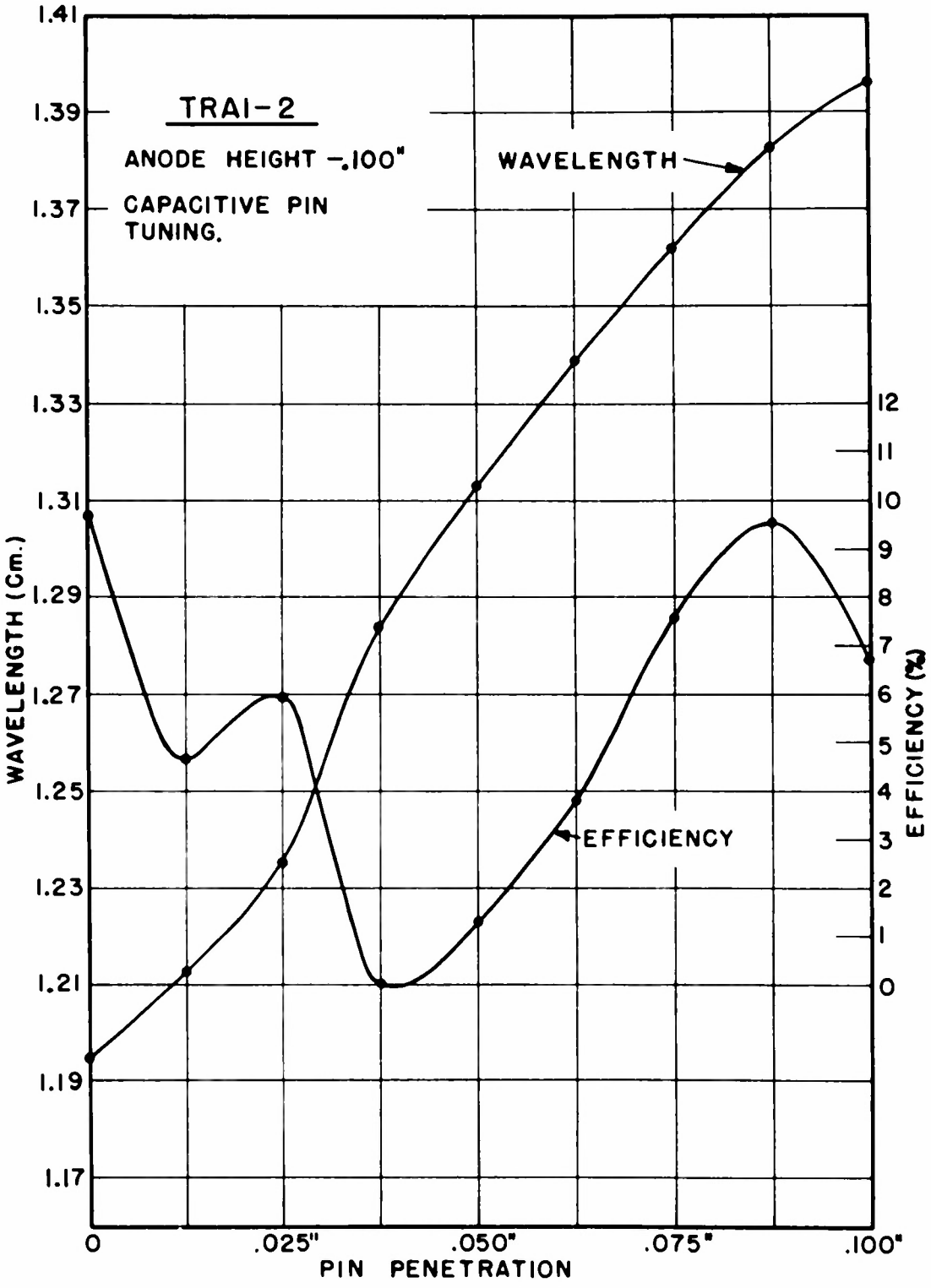


Figure 1. Curves of Wavelength and Efficiency vs. Pin Penetration for Capacitive Pin Tuning.

Another tube, RV1-36 W, contained an .032 in. diameter tungsten coil. Operation was accompanied by moding and arcing. The best efficiency measured was 5.6% at an output of 9.1 watts.

RPB9 Series (22 Vanes, 2.6 mm)

Four new tubes in which the cathode diameter was varied from the size (.029 in.) used in the previous eight tubes have been built and tested.

RPB9-9W

The cathode diameter was increased to .032 in. (σ = .505). There was arcing and moding. About 1kw of power at 2.64 mm was observed. There was an equal amount of power at lower currents in a 3.8 mm mode. Disassembly of the tube showed a badly eroded anode.

RPB9-10W

This tube was a duplicate of RPB9-9W and its operation was very similar. Wavelength was 2.69 mm. At 8.8 peak amperes and 16.1 kv 1kw output at .7% efficiency was measured. Below this current power was observed in a 3.8 mm mode. The cathode emission deteriorated rapidly and after a few hours of operation it was no longer possible to start the tube.

RPB9-11W

The cathode-anode ratio was decreased to .425 (Dc = .027 in.). The emission deteriorated rapidly and no power output was observed.

RPB9-12W

This tube used the same cathode diameter as RPB9-11W. 1.1 kw output at an efficiency of 1% was measured. Wavelength was 2.74 mm. Operation was accompanied by arcing.

It is observed that in the twelve RPB9 tubes tested, serious arcing occurs at voltages above 16 kv. It is believed that this arcing is the cause of the failure of some tubes to operate or of the rapid deterioration of the cathode emission. It is hoped that an anode designed for a 17% lower Vo (6.7 kv), will result in a more efficient and reproducible tube.

The dimensions of this lower voltage anode (RPB10) are as follows:

Number of resonators	22
Anode diameter	.058in.
Small resonator diameter	.081 in.
Large resonator diameter	.1065 in.
Vane thickness	.0045 in.
Anode height	.090 in.

A hob has been ground and several anodes have been hobbed.

F. Generation of Millimeter Waves by Cerenkov Radiation

(M. Danos and H. Lashinsky)

The new vacuum system has been assembled and is being leak tested. In order to eliminate possible sources of electron-induced contamination, the use of vacuum greases and rubber "O" rings has been avoided in the design of the system.[1] All moving joints are made using teflon gaskets or vacuum bellows.

The calculation of Cerenkov radiation has been extended to the case of a complex medium, i. e., one characterized by electric and magnetic susceptibilities which are complex numbers: $\epsilon = \epsilon' - i\epsilon''$ and $\mu = \mu' - i\mu''$. For the case where $\epsilon'' = 0$, the function $\eta(\epsilon,\beta)$ in the expression for the Poynting vector as given in an earlier report[2] has to be replaced by:

$$\eta(\epsilon',\beta,\mu',\mu'') = \frac{\beta(1-\beta^2)\Omega}{\left[(1-\beta^2)^{1/2}\Psi+\beta^2\right]^2+(1-\beta^2)\Omega}$$

where

$$\Omega = \frac{1}{R\mu'(1+\mu'/\mu'')}\left[(1+R)\left(\frac{R+a}{2}\right)^{1/2}+\mu''/\mu'\left(\frac{R-a}{2}\right)^{1/2}\right]$$

$$\Psi = \frac{1}{R\mu'(1+\mu'/\mu'')}\left[\left(\frac{R-a}{2}\right)^{1/2}-\mu''/\mu'(1+R)\left(\frac{R+a}{2}\right)^{1/2}\right]$$

and $R = a^2+b^2 = (\beta\mu'\epsilon'-1)^2+(\beta\mu'')^2$

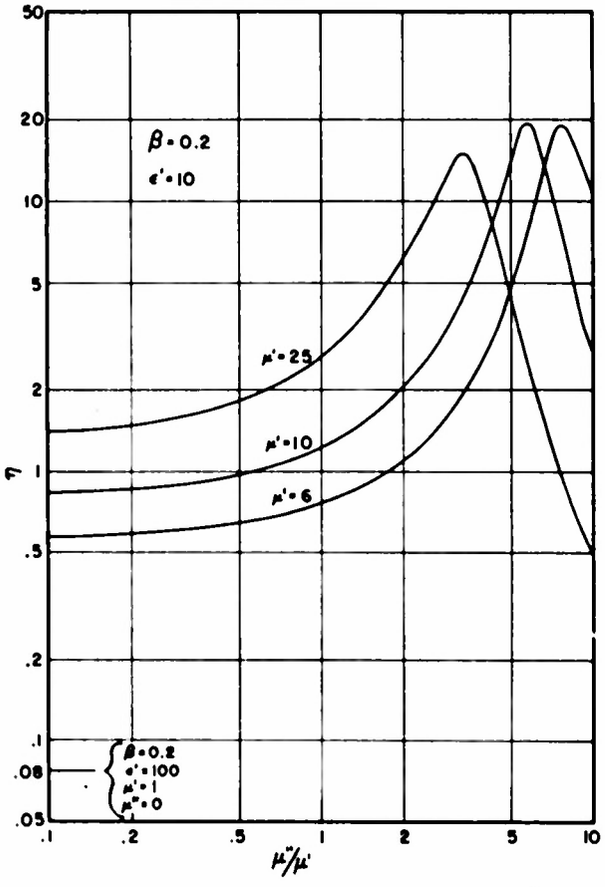


Figure 2. Plot of the function $\eta(\epsilon', \beta, \mu', \mu'')$.

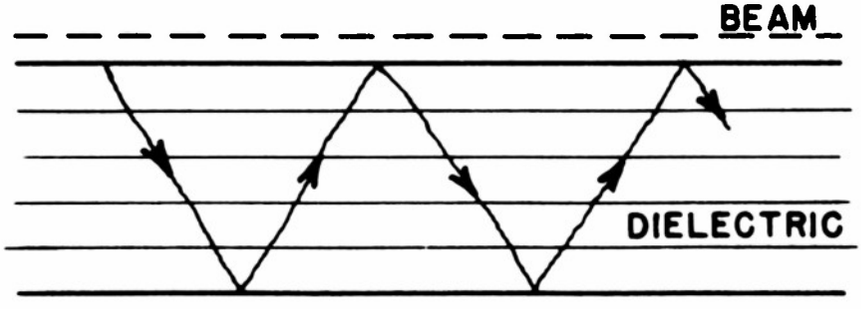


Figure 3. Multiple reflection arrangement.

In Figure 2 is shown the function $\eta(\epsilon', \beta, \mu', \mu'')$ plotted as a function of μ''/μ' for various values of μ' with ϵ' and β held constant. For comparison, the value of $\eta(\epsilon, \beta)$ for the pure dielectric case is also shown. Note that the foregoing does not include the effect of attenuation in the medium and would apply in principle to an infinitely thin strip of the complex medium.

A new experiment incorporating several new features is under consideration at the present time. Among these is the use of a 10 amperes/cm^2 electron beam which would be a factor of one hundred larger than the present beam. Such a high density beam having suitable geometric properties could be achieved only through the use of a high intensity magnetic focussing arrangement. In addition, the use of a multiple reflection scheme with an n of 20-40 as described below is contemplated. It is believed that under these conditions, a very substantial increase in power could be expected.

The multiple reflection scheme referred to above provides for an increase of power by allowing the beam to interact at a suitable phase with radiation already produced. This can be achieved by reflecting the radiation back to the beam (Figure 3). As long as the Cerenkov condition is fulfilled there will be total reflection. The total power output of the multiple reflection arrangement is (n+1) times larger than in the simple arrangement used in the present experiment.[3] Here n is the number of times the radiation has been reflected back to the beam.

1. A. E. Ennos, British Journal of Applied Physics, Vol. 5, No. 1, Jan. 1954.
2. CRL Quarterly Report, Oct. 30, 1953.
3. CRL Quarterly Report, June 30, 1952, see Fig. 2, p. 10.

G. Molecular Beam Oscillator

(J. P. Gordon)

During the past quarter, the apparatus has been operated successfully. The inversion spectrum of ammonia has been partially re-examined and previously unresolved hyperfine structure due to the reorientation of the hydrogen spin has been observed. Lines whose total widths at half maximum are six to eight kilocycles, at 24,000 megacycles, have been observed. In addition, the apparatus has been run as a molecular microwave oscillator, and about 10^{-8} watts of power obtained at the frequency of the J = K = 3 inversion line. This is the first time that energy has been obtained continuously from a molecular resonance. The frequency stability of the oscillator promises to compare favorably with that of other types of "atomic clocks."

At this point it should be profitable to restate the principles of operation of the device as an oscillator. Figure 4 is a block diagram of the apparatus. A beam of ammonia molecules emerges from the source and enters a system of focussing electrodes. These electrodes establish a quadrupolar electrostatic field whose axis is in the direction of the beam. Forces are then exerted on the molecules due to their induced dipole moments, the upper inversion states experiencing a radial inward (focussing) force, and the lower inversion states an outward force. Emerging from the far end of the focusser, there is a beam of molecules virtually all of which are in upper inversion states. The beam then enters a high-Q resonant cavity, in which transitions from the upper states to the lower states are induced.

When the power emitted by the beam in the cavity is adequate to maintain fields of sufficient strength to induce transitions in the beam, then self-sustained oscillation will result. Such oscillations have been observed, and although the power has not yet been directly measured, it is estimated at about 10^{-8} watts.

For spectroscopy, power of varying frequency is fed into the cavity from a klystron, and when the klystron frequency passes the molecular resonance frequency, an increase in cavity power level due to the induced transitions is seen at the cavity output as an emission line.

High resolution is achieved by utilizing the directional properties of the beam. A cylindrical cavity has been used, operating in the TE011 mode. The cavity is twelve cm long, which means that the phase velocity of the radiation in the cavity in the direction of the beam is much larger than C. Thus the Doppler broadening, which is inversely proportional to this phase velocity, is greatly reduced. Analysis shows that the total half width of the resonance line of a molecule traveling with velocity v is about $1.2\ v/L$, where L is the length of the cavity. The most probable velocity in a beam of NH_3 molecules at room temperature is about 4×10^4 cm/sec. This gives a total width at half maximum of four kc, which is close to the six to eight kc widths actually observed.

A typical scope photograph of the 3, 3 line is shown in Figure 5. It demonstrates the previously unresolved satellites, which are themselves doublets, and which are separated from the main line by about 66 kilocycles. The complete hyperfine structure of the 3, 3 line is shown in Figure 6, including the quadrupole satellites, which are also split by the magnetic interactions of the hydrogen nuclei. The finer details of the spectra have not yet been worked out theoretically.

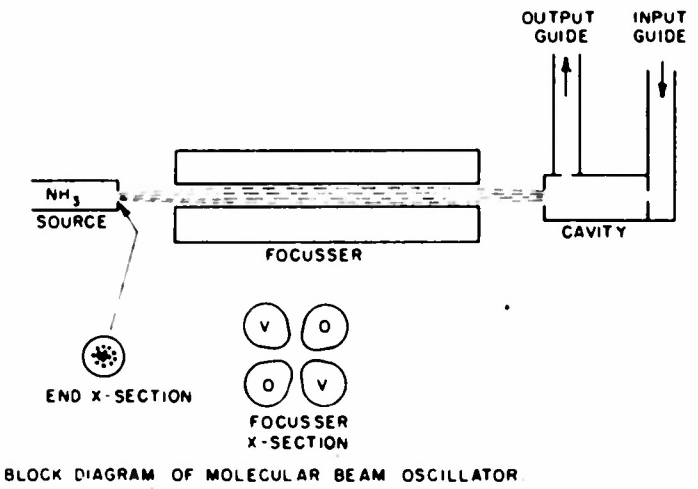


Figure 4. Block diagram of the molecular beam spectrometer and oscillator.

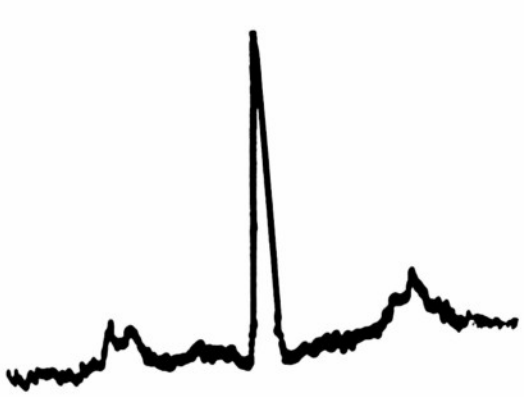


Figure 5. A typical oscilloscope photograph of the NH_3, J = K = 3 inversion line at 23,870 Mc, showing the resolved magnetic satellites.

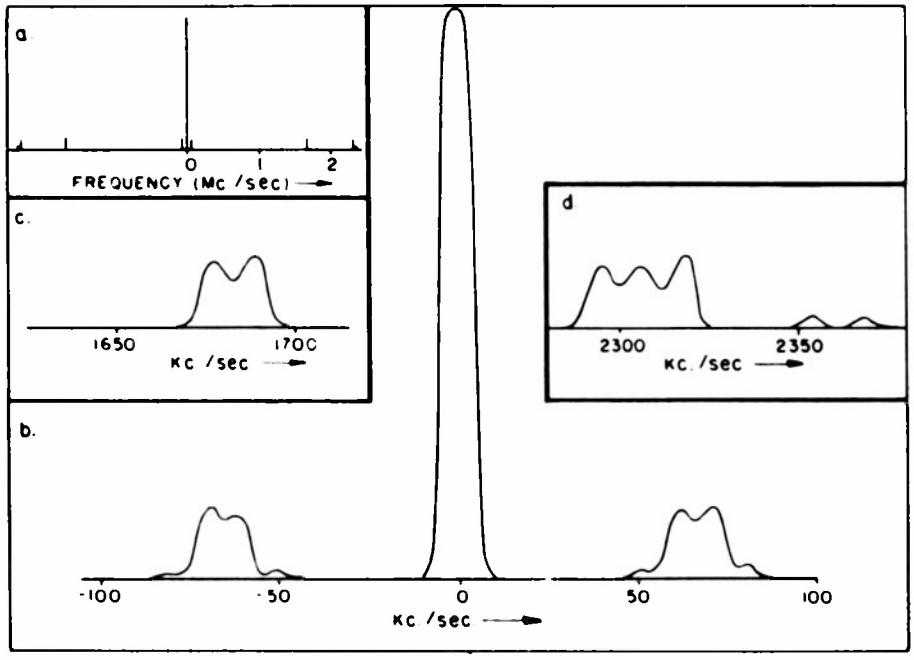


Figure 6. The observed hyperfine spectrum of the 3, 3 inversion line.
a. Complete spectrum, showing the spacings of the quadrupole satellites.
b. Main line with magnetic satellites.
c. Structure of the inner quadrupole satellites.
d. Structure of the outer quadrupole satellites.
The quadrupole satellites on the low frequency side of the main line are the mirror images of those shown, which are the ones on the high frequency side.

This device has considerable potentialities as a spectrometer. Since the effective dipole moments of molecules depend on their rotational state, some separation of rotational states could be effected with a focusser. Similarly, a focusser using magnetic fields, would allow spectroscopy to be performed on atoms. Sizeable dipole moments are required for a strong focussing action, but within this limitation the device may prove to have fairly general applicability for the detection of transitions in the microwave region.

II. MICROWAVE APPARATUS AND TECHNIQUES

A. 6 mm Electronic Spectrum Analyzer

(A. H. Barrett and M. J. Bernstein)

No further work has been done on the 6 mm electronic spectrum analyzer.

B. Crystal Harmonic Generators and Detectors

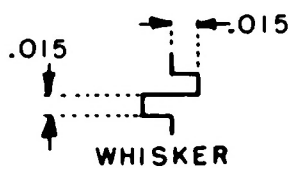
(W. R. Bennett, A. H. Nethercot, Jr., and B. Rosenblum)

In order to improve the techniques for the generation and detection of millimeter waves, investigations of several phases of the problem are in progress.

1. Effect of Contact Pressure on the Harmonic Generator.

The output of the crystal harmonic generator has been measured as the pressure at the contact of the cat whisker and silicon crystal was varied. The data were taken at both the second and third harmonics of 1.25 cm wavelength, the behavior at these two harmonics being very similar.

A differential screw mechanism was used so that the pressure could be increased in small steps by advancing the far end of the 2 mil diameter whisker. This was done in steps of 3/4 mil advance of the differential screw. At each setting of the differential screw, a calibrated attenuator was slowly retracted so



that the harmonic power could be measured as a function of the incident fundamental power. The power-out versus power-in curves were presented on an oscilloscope and photographed. Six different contacts were investigated, data being taken for deflections of the whisker from first contact up to a maximum of from 8 to 23 mils of screw advance.

A typical set of data is shown in Figure 7a. It is seen that neither the maximum harmonic power available nor the point of saturation is very dependent upon contact force. For light contacts the harmonic power decreases markedly at high incident powers while it remains constant for heavy contacts.

The data can be replotted to show the harmonic power versus whisker deflection, with incident power as the parameter. A typical set of curves is shown in Figure 7b. The first contact is usually the best. The harmonic power generally decreases from that at the initial contact by a factor of about 1.5 when the screw is advanced 2 or 3 mils. Further motion of the screw usually increases and decreases the harmonic power within the above values once or twice more.

The major conclusion that can be drawn from this work is that contact force in the harmonic generator is not a particularly significant parameter for second and third harmonics.

2. Effect of Sharp Points on Harmonic Generators and Detectors.

The differential screw mechanism has now had considerable use in this laboratory, both on the harmonic generators and detectors. The electropointing procedure has been improved so that almost all points leave the pointing bath with a radius less than 10^{-5} inches. Even with the most extreme caution to insure that points are undamaged and that first contact is just made, the amount of power previously obtained at harmonics up to the eighth has not been exceeded by the new devices. The previous results were obtained with considerably blunted points and much larger contact forces.

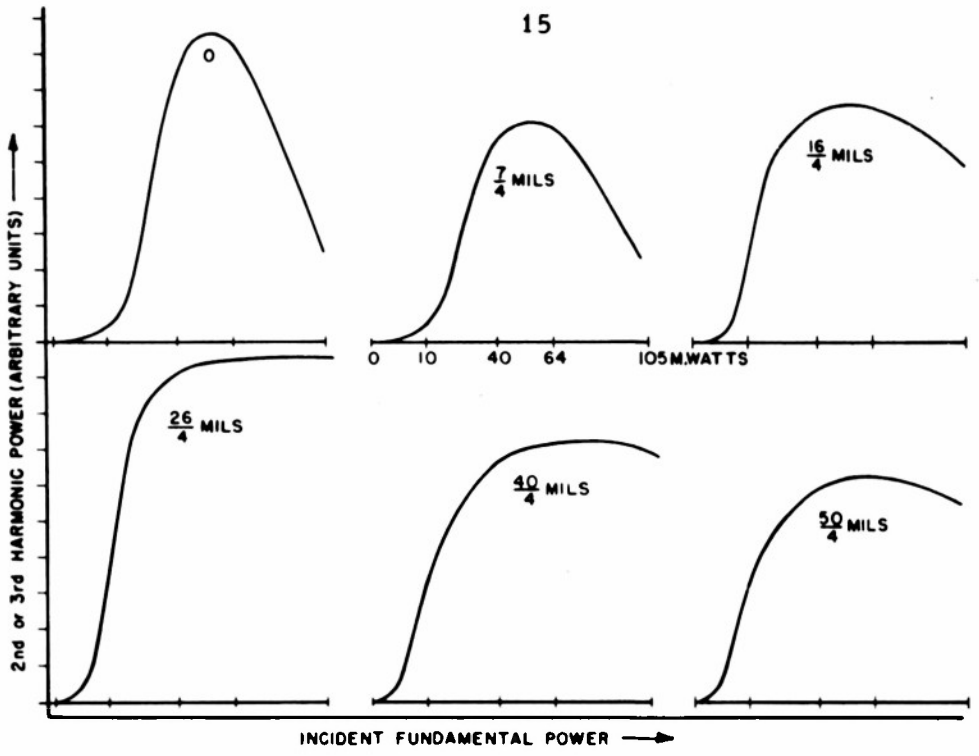


Figure 7a.

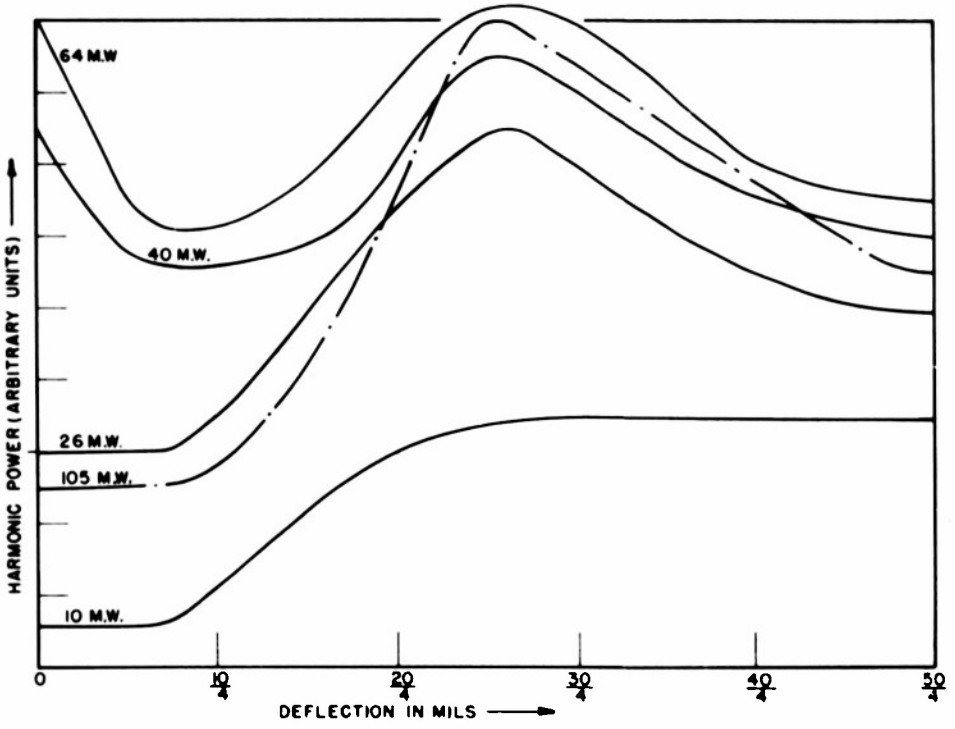


Figure 7b.
The effect of whisker deflection on crystal harmonics.

III. TUBE FABRICATION TECHNIQUES

Hob Grinding and Hot Hobbing

(M. J. Bernstein and C. O. Dechert)

A 22 vane vitallium hob for RPB10 (2.6 mm) tubes has been completed during the past quarter. Dimensions are as follows:

Anode diameter	.058 in.
Small Resonator diameter	.081 in.
Large Resonator diameter	.1065 in.
Vane thickness	.0045 in.

Four anodes have been pushed. At 725°C approximately 300 pounds force is required to penetrate .150 in. into the copper.

IV. MICROWAVE PHYSICS

A. Hyperfine Structure of the Hydrogen Atom

(J. Heberle, P. Kusch, and H. Reich)

1. New Detector.

It has been found necessary to construct a new detector because the previous one projected too far into the interaction chamber to permit the installation of the second rf flopper. This detector was built with as low an input capacity as possible, so as to permit the use of a large grid resistor and still keep the time constant low. With a resistor of 202,000 megohms a time constant of 4.1 sec results. The sensitivity of this detector, which uses a VX41-A electrometer tetrode, is 0.89×10^{-16} amperes/mm at two meters. Typical metastable beam intensities are in the region of 3×10^{-14} amperes.

2. Rf Resonances.

A rough attempt was made to observe the Ramsey[1] pattern using two rf floppers 8 in. apart. The field-independent line has a half-width of 20 kc, which is consistent with a velocity of 7×10^5 cm/sec.

Rf resonance curves taken with currents from 30 to 40 amperes in the polarizer and 35 to 45 amperes in the analyzer show no significant variation.

3. Wood's Tube.

The present dissociator runs at a temperature of 2800°K and the observed lines are broad.

One way of reducing the line width is to reduce the velocities of the atoms in the beam. By using a Wood's discharge tube to dis-

sociate hydrogen the mean velocity of the atoms, and consequently the line width, will be reduced by a factor of 3. Accordingly, a discharge tube, designed by Mr. Eugene Commins of Watson Laboratories, is being built.

1. Phys. Rev. 78, 695 (1950).

B. Fine Structure of the Singly Ionized Helium

(N. Kroll, E. Lipworth, M. McDermott, and R. Novick)

1. The new vacuum system has been assembled and partially leak tested. Two difficulties have manifested themselves:

a. The nickel plating in and around the large "O"-ring grooves on the liquid air traps had a tendency to peel away. The plating in these regions has been removed to avoid any difficulty with the seal.

b. The Kel-F coated "O" rings which were to be used throughout the system[1] have proved unsatisfactory. Under pressure sufficient to obtain a seal the Kel-F coating has a tendency to crack at the joint.

At present seals are made with convaseal rubber "O" rings which in the future will be replaced by moulded teflon rings.

2. The freon refrigeration system is now in operation, but the mercury pumps have not yet been activated. The 1/3 hp compressor is of sufficient power to cool the baffles down to approximately -10°F. It is hoped that this temperature will be low enough to insure that the main bulk of the mercury vapor is trapped.

3. The magnet regulator[2] is now in operation. A new field coil for the magnetron current sensing element has been wound and the field current can be varied from 4.2 to 12.2 amperes in four steps, corresponding to an overall field range of 10,250 to 18,600 gauss. A rough preliminary measurement indicates that the field is stable to 1 part in 10,000.

4. A basic change in the method of accumulating data is being considered. The experiment as performed so far has made use of a time separation technique to improve the signal-to-noise ratio, the production of metastable ions and the observation of

transitions therein being separate and discrete processes. This scheme has had the disadvantage of considerably complicating the electronic problems that have had to be solved, but was unavoidable in view of the low average powers that could be obtained from the rf source. Due to the fact that we now possess a resonant interaction space with a considerable power gain (120), it may be possible to make use of a method of synchronous detection that would considerably ease the requirements upon the electronics, and in addition simplify interpretation of the data.

It is proposed, therefore, to adopt a scheme of simultaneous excitation and observation. Excitation will be produced by continuous bombardment of helium gas while the significant signal will be induced by a square wave modulation of the klystron rf source at a 10 kc rate. Rather than use the standard narrow band amplifier techniques to improve the signal-to-noise ratio we propose to make use of high speed counters in the following way. When the rf is "on", counter I will be operative and counter II inoperative; when the rf is "off", counter II will be on and counter I off. Precisely the same degree of information can be obtained from this arrangement as from a lock-in scheme with narrow band detection, but with the advantage that the observed signal can be reduced to a standard rf off count, i.e., a normalization procedure is possible. The above use of counters was suggested by Dr. M. Danos of this laboratory. Below is summarized the probable advantages and disadvantages of the proposed scheme.

Advantages

a. The problem of pulsing the klystron will be greatly simplified; some critical timing circuits will be eliminated.

b. A steady state ion distribution will exist in the interaction region which should simplify considerably the analysis of the variations of the ion removal rate with magnetic field.

Disadvantage

A certain amount of information will be lost. For example it will no longer be possible to study ion removal directly as the bombarding current is varied, and such an interesting phenomenon as "negative flop" will no longer be observable.

1. CRL Quarterly Report, Aug. 31, 1953, p. 18.
2. CRL Quarterly Report, Jan. 30, 1954, p. 17.

C. Nuclear Quadrupole Resonant Lines

(T. C. Wang)

The rf system was set up for an investigation of the quadrupole resonances of Cl in chloro-germane and sufficient chloro-germane for a run was prepared by Dr. G. Silvey of this laboratory. Because of unavoidable impurities in the sample no lines have yet been observed.

A study of the effect of the impurity on the quadrupole resonance was made by mixing some para-dibromobenzene into para-dichlorobenzene. The result indicated that only five percent impurity in molecular number would decrease the quadrupole signal to 1/10 the signal of Cl^{35} from pure polycrystalline para-dichlorobenzene.

D. Very High Temperature Microwave Spectroscopy

(A. H. Barrett and M. Mandel)

An attempt has been made to observe the microwave spectrum of KF but considerable difficulty was experienced with shorting of the Stark septum. Five lines were detected at a temperature of 775°C but it was not possible to take sufficient data to identify them positively as being due to absorption by KF. The excessive shorting of the Stark septum could be due to the alkali fluoride,[1] or to a slight modification in the water cooling system which inadvertently prevented sufficient thermal expansion of the guide, thus causing warping and the subsequent shorting of the septum. The latter has been corrected and it is intended to attempt to operate with KF again at some future date.

Several runs have been made on AgI, and 22 lines were observed in the range from 20.8 - 25.5 kMc over a temperature range of approximately 450°C - 550°C. These lines were not those of a diatomic molecule and appeared independent of temperature. It was subsequently noted that all the lines corresponded to the known lines of NH_3,[2] within the accuracy of the wavemeter readings. A short run was made with AgCl and again the NH_3 lines appeared. Furthermore, it has been reported that TlCl,[3] InCl,[4] and HgFCl[1] failed to yield the expected lines and it was found that all the observed lines (except 2 lines in TlCl) were due to NH_3. The presence of NH_3 in the apparatus during any of these runs is unexplained.

The resistance between the Stark septum and the guide has diminished considerably during the runs on AgI and AgCl and the apparatus is being taken apart for repairs.

1. Honig, Stitch, Mandel, and Townes, CRL Quarterly Report, March 31, 1953, p. 17.
2. Kisliuk and Townes, Molecular Microwave Spectra Tables, N.B.S. Circular 518, June 23, 1952, p. 84.
3. Stitch, Honig, and Townes, Bull. Am. Phys. Soc. 27, No. 1, 32 (1952).
4. Stitch, Honig, Mandel, and Townes, CRL Quarterly Report, December 31, 1952, p. 25.

E. High Resolution Spectrometer

(R. L. White)

A survey of magnetic coupling in $^1\Sigma$ molecules has been completed. A paper on these results and their analysis is being prepared.

F. Free Radical Experiment

(G. C. Dousmanis)

Microwave spectroscopy of free radicals may prove to be a useful technique in obtaining information about their properties such as their lifetimes and reactivities with other substances. The efficiency of various methods of production and detection of the radicals could also be investigated.

In the present experiment results bearing on the methods of detection of OH have been obtained and have already been published.[1] During the past quarter tests have been made to determine whether the presence of certain substances in the path of flow of the OH radicals affect the concentration of OH, as determined from the intensity of the microwave lines. The OH concentration would decrease if a particular substance either directly combines with OH or simply provides a convenient surface for recombination of the radicals.

The sample to be tested was attached to the end of a glass rod and introduced into the tube connecting the discharge tube, where the radicals are produced to the absorption cell. Line intensities are measured with the sample in and out of the path of the gas flow, all other conditions being the same. The following substances decrease greatly the OH concentration: copper, graphite, nickel, and kovar.

Substances which do not appreciably affect OH: apiezon wax, teflon, glyptal, potassium chloride, aluminum. Mica is found to decrease the OH concentration, but not as effectively as members of the first group. The substantial help of Mr. W. A. Hardy in carrying out these tests is appreciated.

The fact that aluminum does not affect the OH radical (presumably because of the oxide coating of the metal surface) suggests the feasibility of building an aluminum absorption cell. As a further test a 3 inch section of the glass tube connecting the discharge tube with the absorption cell has been replaced by an aluminum tube and again no decrease in line intensity has been found. It has therefore been decided to construct an aluminum Stark cell with which we expect to observe the Stark effect in OH, and which may also be used for spectroscopy of other radicals. The design of the system is that of a conventional Stark cell; teflon windows, reinforced on the outside by mica are used. The inside dimensions of the guide are 5/8 in. x 1 3/8 in. (intermediate between S and X bands). The system has been assembled and is now being tested.

Some efforts have been made to observe the microwave spectra of SH. We attempted to produce SH by an rf discharge through H_2S. Sulfur was deposited inside the vacuum, but it has been found that such a deposit can be easily removed by passing through the system atomic oxygen produced by an rf discharge on O_2. Various byproducts of both of these discharge processes condense on the liquid nitrogen trap. During one of these runs in the smaller of the two Zeeman cells enough of these by-products was accumulated to cause a detonation in the trap, of sufficient strength to damage the glass system. The larger Zeeman cell was unimpaired.

1. Sanders, Schawlow, Dousmanis, and Townes, J. Chem. Phys. 22, 245 (1954).

G. Polymeric Content of Alkali Halide Beams

(R. C Miller)

The additional collimating slits mentioned in the last Quarterly Report were found to be impractical. Vibration caused by the rotor produced serious unsteadiness in the beam. Sufficient enlargement of the collimating slits to reduce variations in beam intensity consequent to vibration reduces the collimation of the beam to the point where the slits no longer serve to prevent possible reflection from the rotor surfaces, so the slits were removed.

After making a few changes at the oven end of the apparatus, the persistent temperature discrepancy between the beam temperature (calculated from the velocity distribution) and the oven temperature (measured with a thermocouple) was removed. The more important modifications were the addition of a liquid nitrogen trap to the oven chamber, thereby improving the vacuum by a factor of about ten, and the use of oven slits made from 0.0015 in. thick steel sheet clamped on the oven face with OFHC copper strips. Runs using potassium and thallium, both producing essentially atomic beams, showed the temperature discrepancy could be reduced to experimental error, a little less than one percent of the temperature. Agreement between experimental and theoretical velocity distributions for moderate beams was good enough to rule out the possibility of significant velocity dependent scattering from the walls of the velocity selector slots. Thus it appears that the proposed collimating slits were not necessary.

Returning to the original aim of the project, some alkali halide beams were investigated using the two chamber oven. Cesium chloride and cesium bromide beams were found to be monomeric over the range of oven temperatures and pressures experimentally feasible. The smallest amount of dimer which could be observed is about three percent of the total detected beam (one and one-half percent of the molecules coming from the oven).

Rubidium iodide and potassium iodide beams consisted of less than about 8 percent dimer, so that the uncertainty in the amount of dimer was quite large. It has been decided to look at these compounds again, using a single chamber OFHC copper oven incorporating the 0.0015 in. slits. This oven would yield the largest amount of dimer for a given oven temperature. Then with better data, a reliable value for the dissociation energy of the dimers can be obtained.

Data were also obtained for sodium iodide and lithium bromide. Sodium iodide beams showed dimerization amounting to as much as 24 percent of the detected beam, and lithium bromide up to 78 percent of the detected beam. Preliminary calculations gave 1.83 e.v. for the dissociation energy of the sodium iodide dimer, $(NaI)_2$, and 2.08 e.v. for $(LiBr)_2$.

No attempt has been made using theoretical arguments to relate these preliminary results to other information on alkali halides. From the general trend of the data, it appears that dimerization increases with decreasing atomic weight of the alkali atom in the salt, but is fairly insensitive to the halogen component.

H. Millimeter Wave Spectroscopy

(A. H. Nethercot, Jr. and B. Rosenblum)

A hood and exhaust fan have been completed so that the spectra of various radioactive gases can be examined safely in the millimeter wavelength range. Work directed toward obtaining higher harmonics from the crystal harmonic generators for spectroscopic use is continuing.

I. Magnetic Resonance at Millimeter Wavelengths

(F. M. Johnson and A. H. Nethercot, Jr.)

Absorption lines in $NiK_2(SO_4)_2 \cdot 6H_2O$ in the 2.5 mm wavelength region have been observed. Further observations of the magnetic field at which the resonance occurs as a function of temperature and frequency must be made in order to clarify the experimental situation.

J. Superconductive Surface Resistance at Millimeter Wavelengths

(R. Kaplan and A. H. Nethercot, Jr.)

In order to measure accurately the superconductive surface resistance it is necessary to have an unstrained surface which is smooth to a small fraction of the skin depth ($\sim 10^{-6}$ cm). Electropolishing is the only technique which will produce such a surface.

A great deal of time has been spent during the last quarter in electropolishing the tin, using the method of Jacquet,[1] which involves a polishing bath of perchloric acid and acetic anhydride.

The surfaces polished so far have not been too satisfactory, inasmuch as they scatter light diffusely on visual inspection and show a slight roughness under a 300 power microscope. The reasons for this comparative lack of success are not evident, and correspondence with authorities in the field fails to reveal the cause of the difficulty. Further work must be done on this point.

However, it has been decided to perform the experiment with the best surface prepared to date, and assembly of the cryostat with this sample is now in progress. This should give preliminary results on the skin resistance, and, if a photoelectric threshold for conversion of superconducting to normal electrons does occur, it should at the very least be revealed with this tin sample.

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1. Publications of the International Tin Research and Development Council, 90 (1939).

V. ELECTRONIC APPARATUS AND TECHNIQUES

Klystron-Pulsing Unit

(A. W. Costello and H. Lashinsky)

Because of a change in the detection system of the helium fine structure experiment (see p. 19), the requirements for the klystron keyer unit described earlier[1] have been modified. The new specifications call for a 10 kc square-wave with rise and fall times of about 0.05 μsec and an amplitude of about 500 v. At this repetition rate it is expected that the above requirements can be easily met by a unit employing hydrogen thyratrons.

1. CRL Quarterly Report, Jan. 30, 1954, p. 23.

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